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AN AUSTRALIAN INSENSITIVE MUNITIONS POLICY: A WORKING PAPER PREPARED FOR THE AUSTRALIAN ORDNANCE COUNCIL

Robert J. Spear and Louise M. Davis*

* Weapons Systems Research Laboratory

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ABSTRACT

This report has been prepared in response to a request from President, Australian Ordnance Council (PAOC), for a working paper to serve as a basis for derivation of an Australian policy on Insensitive Munitions (IM). IM are defined (Section 2) and the background studies confirming the operational and strategic benefits are summarised (Section 3). Overseas service/user policies are described (Section 4), particularly those of the US Navy which has the most clearly defined IM policy. Ten questions from PAOC dealing with background issues, priorities, possible cost penalties and methodology for meeting IM guidelines, Australian production capabilities and current and future R & D, implementation timescale and impact on munition exports and collaborative programs are answered (Section 5). Policy options are presented (Section 6) followed by a summary and recommendations for implementation such that the potential benefits from IM for Australia's defence preparedness and self reliance can be achieved (Section 7).

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POSTAL ADDRESS: Director, Materials Research Laboratory
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

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FOREWORD

This document was prepared in response to a minute from President, Australian Ordnance Council (PAOC) [1], which requested a working paper to be used as a guide for the formulation of Insensitive Munitions (IM) policy. The paper initially describes background issues, discusses US and UK policies on IM, provides answers to the specific questions requested by PAOC [1], and outlines a range of policy options which could be adopted by Australia.

Although primarily a technical document, attention is drawn in appropriate places to the potential of IM to substantially enhance Australia's defence preparedness, using as a guideline "The Defence of Australia (DOA87)" [2].

1. INTRODUCTION

For most of this century the principal goal of weapons designers has been to increase cost-effective performance-on-target. The introduction of RDX into warhead formulations just prior to WWII, and subsequently HMX in the 1950s, and of increased energy propellants for projectiles and rockets, have been key elements in this process over the last 50 years. Replacement of explosive and propellant formulations has also occurred to improve thermal or chemical stability so that the life of munitions can be extended, or so they can be used in more severe environments, eg to resist the effects of aerodynamic heating.

The outcome of this policy is that a modern munitions inventory consists of ordnance with high performance but also, in many cases, relatively high vulnerability to

hazardous stimuli that may be experienced during production, transport, storage and operational use. In addition, response to these hazardous stimuli is often extremely violent, ranging right through to detonation. Some of the major disasters that have occurred over the last 25 years following accidental initiation of ordnance are detailed below.

US Aircraft Carrier Accidents, 1966–1981

The USS Oriskany, Forrestal, Enterprise and Nimitz were all involved in separate incidents involving ordnance over the period 1966-1981. Details are provided in the following table; loss of life and materiel was high in all cases.

Carrier	Date of Accident	Personnel Dead/Injured	Aircraft Destroyed/Damaged	Cost* (US$)
Oriskany	10/66	44/156	3/0	10 M
Forrestal	7/67	134/161	21/43	72 M
Enterprise	1/69	28/343	15/17	56 M
Nimitz	5/81	14/42	3/9	58 M

* Costs incurred at that time, not corrected to current cost. The figure for the Enterprise does not include aircraft replacement.

US Munition Train Accidents, 1969–1973

Over the period 1969-1973 three major accidents were caused by fire on a boxcar leading to cook-off of ordnance carried in that car. The resulting blast caused munitions in adjacent boxcars to sympathetically detonate. The major accident was at Roseville, California, where over 250,000 kg of bombs detonated. Details are given below; amazingly, no one was killed in any of the accidents.

Place	Date	Munitions Detonated
Towbar, Nevada	6/69	2 boxcars M117 bombs, Minol 2 filled
Roseville, California	4/73	18 boxcars Mk 81 bombs, Tritonal filled
Benson, Arizona	5/73	12 boxcars Mk 82 bombs, Tritonal filled

Pakistan Ammunition Depot Explosion, April 1988

An explosion at an ammunition transport depot sited between Islamabad and Rawalpindi resulted in probably over 1000 dead. Many thousands of medium and small arms were destroyed, with projectiles raining down on the two cities over 15 km distant.

Pershing First Stage Motor Fire, West Germany, January 1985

During a training exercise a Pershing rocket motor ignited during loading. Three personnel were killed and 16 wounded. The probable cause was electrostatic discharge which ignited the propellant grain.

It is generally accepted throughout the Western Ordnance Community that the effects of these incidents would have been reduced, and in some cases prevented, if modern insensitive energetic materials and current insensitive munitions design philosophy were available and in use at the time.

2. DEFINITION : INSENSITIVE MUNITIONS (IM)

Insensitive munitions are those munitions which reliably fulfill their performance, readiness and operational requirements on demand, but which will minimise the violence of a reaction and subsequent collateral damage when subjected to unplanned heat, shock, electromagnetic energy, or radiation [3].

The term munitions refers to all explosive ordnance including bombs, missiles, torpedoes, mines, pyrotechnics, demolition charges and special purpose devices.

3. BACKGROUND

The enhancement of defence preparedness via improved system survivability and operational safety resulting from the introduction of IM has been confirmed by a number of studies, particularly in the US. The three described below were the key initial study and two which had, or are having, Australian participation.

3.1 US Insensitive High Explosives and Propellants (IHEP) Study 1978-79 [4]

In June 1978, as a result of a letter of intent from US Deputy Undersecretary of Defense for Research and Engineering to Dr H. Agnew of Los Alamos National

Laboratory, the US DoD and DOE agreed to undertake a joint effort to study the utility of IHEPs in some typical DoD conventional weapons systems. The overall study objective was to describe to the Secretary of Defense what IHEP program options were suitable for both the near and long terms to improve overall survivability of the conventional munition stockpile.

Specific objectives were:

- assess advantages and disadvantages of using IHEP in conventional weapons
- identify near term opportunities for application of IHEP to selected weapon systems
- determine the impact of new IHEP on munition production facilities
- determine incremental and total life-cycle costs of acquiring weapons containing IHEP.
- assess impact of new IHEP on the logistic cycle
- identify near and long term IHEP research and development requirements

The study was limited to energetic materials which could be interim qualified in about two years, and fifteen weapons systems/platforms. The study team considered munitions through virtually every step of life cycle from inception to retirement. Selected conclusions and recommendations of the study most relevant to Australia's defence preparedness are described below.

1. Significant improvements in operational safety and survivability, as well as logistic cost, can be achieved without loss of performance-on-target through an expanded use of IHEP in US munitions. For example:

   Tanks/APCs/ground launched rockets; substantial reduction* or elimination of catastrophic (K-Kills) losses and reduction in total losses.

   Helicopters/F-4 aircraft; small to substantial reduction in vulnerable area.

   Shipboard magazines; moderate to substantial reduction in sink probability to missile attack.

2. The improvements described in 1 are for the most part not attainable at this time (1979) because neither the underlying development work nor the production base is in place to support a transition to these materials.

3. DoD should establish high priorities for a transition to IHEP where careful analysis indicates operational and cost advantages.

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* Actual numbers are given in the classified report [4].

4. DoD-supported R & D on explosives and propellants has been funded in too fragmented a fashion and at too low a level. Many aspects of conventional weapons systems, including vehicles, guidance systems and countermeasure technology, properly receive considerable attention and resources. However, for the conventional wars of today and the future, it is the on-target performance of the explosive, and the survivability of the weapon system, that is the bottom line. R & D on energetic materials are directly related to these important factors.

3.2 WAG-7: Insensitive High Explosives and Propellants 1980-81 [5]

This study, under the auspices of TTCP Subgroup W (Weapons Technology), was designed to continue the impetus generated by the IHEP study [4]. The decision was made to concentrate on two major topics.

1. Formulations of gun propellants, rocket propellants and explosives.
2. Response of munitions to threats such as cook-off, fragment attack and mass detonation.

All four TTCP member countries were actively involved, although at the time there was minimal relevant R & D in Australia and our participation was low.

The WAG-7 study fully confirmed the potential benefits identified in the IHEP study [4]. It was clear that technology gaps still prevented full realisation of IM goals. Identification of a number of explosive formulation and munition response areas as being productive and ripe for major advances in achieving IM status in weapon systems was made. These are listed below:

- energetic binders and insensitive formulations.
- mechanical properties and their effect on munition survivability.
- processing, especially of explosives and including melt-cast systems.
- cookoff, response of munitions to fragment attack, and mass detonations.

The WAG-7 Action Officers made recommendations on continuing interactive programs. However, the reluctance of the propellant community at that time to be fully involved resulted in WAG-7 not achieving its full potential, and the demise of the follow-on programs. The attitude of the propellant community at that time (particularly in the US) is understandable since closer affiliation with the explosives community carried the potential for propellants to be required to pass the far more extensive hazards assessment testing routinely required for explosives.

3.3 WAG-11: Hazards of Energetic Materials and their Relation to Munitions Survivability 1987-1991 [6]

By late 1986 the climate had changed, particularly in the US Navy (see later), such that the introduction of IM was seen as firm policy. The US propellants community now consisted of a new generation of R & D personnel willing to address the hazards of current and proposed weapons systems and materials. Consequently, under the auspices of TTCP Subgroup W, WTP-1 (Terminal Effects) and WTP-4 (Propulsion Technology) set up WAG-11. A description of the WAG objectives follows; this is taken substantially from the Introduction in [6] and represents a clear, concise statement of the benefits of IM.

The problem of munitions survivability, although always present, has only recently received much overdue attention. While the solution to the problem will require a full spectrum approach including system design and storage considerations, the energetic materials themselves remain a key element. The problem exists throughout the complete life cycle of the munition including manufacture, transport, storage and operational use. Although much emphasis has been placed on the so-called "cheap kill" scenario in combat situations, recent experience has revealed severe problems in storage and training that are both as devastating and more immediate than war scenarios. Modern technological advances have seen propellants and explosives develop many more similarities than in the past. The melding of the technological approaches of these two communities is an appropriate and efficient way to address the role the energetic material plays in munition survivability.

Benefits are anticipated at several levels, some of which have been mentioned above. Throughout the entire life cycle of the munition, safety/survivability improvements will produce real cost benefits as well as reduced personnel risks. These cost benefits will arise from more realistic quantity/distance rules that minimise the amount of real estate necessary for storage. The reduction in overall munition response, resulting from an accident or terrorist attack, will also lead to reduced loss of life, damage and subsequent replacement costs.

The results (of WAG-11) will provide significant benefits in the areas of standardisation and interoperability. Nations that share a common hazards test program and philosophy will find the hazards evaluation of participating nations' weapons far easier, timely and economical. Hazards assessments are national requirements. Common tests and philosophy in hazards evaluation will aid in the promotion of international weapons exchanges, multi-national weapons development, and interoperability.

The technological benefits from this study will significantly affect the development of future munitions. Given that survivability/safety/invulnerability strictures will not be relaxed (and most likely will increase), a methodology to determine hazards parameters becomes even more important. While large scale testing will probably always be necessary as a proof of principle, it is much too expensive and cumbersome to use in the initial development stages. Yet it is at those initial stages where the information on hazards and performance are most critical. The development of a set of rational, predictive, small-scale tests and the technology to support them will provide those early-on hazards and performance estimates. Being small-scale they will be relatively economical, and by being rational and based on a sound technology base they will be reliably predictive and applicable to new types of energetic materials and to

new requirements. This promises to reduce costly failures late in the development cycle for new weapons and to reduce the time necessary for their successful development.

In wartime scenarios, weapons storage on combatants (principally ships) can be increased thus extending operational periods. Cheap kill scenarios have been mentioned previously. Increased survivability of weapons against enemy countermeasures will increase weapon and platform combat effectiveness.

Five technology areas, each representing a realistic hazard threat, are being investigated by WAG-11.

1. Sympathetic Detonation
2. Bullet/Fragment Impact
3. Shaped Charge Impact
4. Electrostatic Discharge*
5. Cookoff

A workshop on areas 1-4 was held in the UK in July 1988. Technology areas for cooperation were identified and cooperative programs have subsequently been implemented. A workshop on cook-off and a discussion of progress in the other threat areas will be held in Australia in March 1989.

4. CURRENT OVERSEAS SERVICE/USER POLICIES

In section 3, the potential of IM to enhance safety and operational effectiveness was outlined. The technology is now sufficiently advanced to solve many of the current hazard problems using a combination of approaches (materials, mitigation devices, system redesign etc). Australia's high value sea and air platforms, which are a major component of our defence strategy [2], would be enhanced in combat survivability and hence effectiveness if their weapons systems were IM. Australia could adopt one of a number of IM options; these are presented in more detail in Section 6 following the answers to questions from President AOC. The IM policy of the US Navy is the most clearly defined in terms of technical requirements and timescale, and accordingly is reviewed below in considerable detail. Policies of the US Air Force and Army, the UK and NATO countries, which are less defined, are only summarised in the following subsections.

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* In the following sections ESD is not mentioned nor is it a requirement for IM; ESD is principally a safety problem, although an IM would also presumably be insensitive to this stimulus.

4.1 US Navy Policy

Not surprisingly, given the disastrous aircraft carrier accidents cited in Section 1, the US Navy has shown great concern to both improve platform (ship and aircraft) vulnerability in war, and to enhance aircraft carrier survivability against fire.

In the late 1970s, following the US IHEP study [4], Admiral Watkins, then Vice Chief of Naval Operations (VCNO), tasked NAVSEA to improve the design of all munitions carried by the Navy so as to reduce sensitivity to unplanned heat or shock. The major constraint was that any new design should not degrade performance.

The program was slow to develop and did not address the total problem. In 1984, Admiral Watkins, by this time CNO, accelerated the program with funds totalling US $300M to be spent between FY 84 and FY 89. A clear and concise policy statement was officially issued [3], and is produced below in its entireity:

Policy: All US Navy munitions, in their end item configuration, will be designed to minimise the effects of unplanned stimuli. They will incorporate insensitive energetic materials which meet or improve upon published insensitivity standards. Mitigation devices will also be used, where appropriate, to decrease vulnerability of the munition to unplanned stimuli. The Navy goal for complete arsenal transition to insensitive munitions is 1995. Wherever feasible, this goal will be achieved earlier. All programmatic milestone reviews for munitions will specifically address the sensitivity issue including cost and alternatives. Operational capability must be maintained, but every effort must be made to meet operational requirements with the least sensitive material available.

A command structure to implement the policy was also established [3] and subsequently the logistics of the program were proclaimed [7]. In addition to reiterating the goals of Reference [3], guidelines for design modifications and new program concept development were laid down [7].

A Navy-wide program plan was subsequently issued [8] to provide management and guidance for the overall IM Program, as well as specific Navy IM programs such as the Weapons Programs and the Insensitive Munition Advanced Development (IMAD) Program. In particular, a technical approach to achieve insensitivity was outlined; included were new high explosives, warheads with passive or active mitigation techniques, fuzes including those with active mitigation, new propulsion systems and improved pyrotechnics. Also outlined was a program execution plan, including priorities and completion dates for current weapons systems to achieve IM status (see Section 5.5), hazard assessment, plans of action and milestones, and waiver procedures.

Achievement of IM status requires final (type) qualification of the all-up weapon system/round [9]. The technical requirements are established in reference [10] (particularly Appendix D); emphasis is placed on meeting these requirements through "the use of effective yet insensitive energetic materials qualified in accordance with Reference [9]" [10]. These requirements are:

1. a total systems safety program [11], including general test requirements such as environmental storage outlined in [12],

2. additional hazard assessment test requirements [12], as listed below:

Bullet Impact	No reaction more severe than burning
Fast Cookoff	No reaction more severe than burning
Slow Cookoff	No reaction more severe than burning
Fragment Impact	Sensitivity assessment; no reaction more severe than burning
Sympathetic Detonation	No propagation in stowage environment
EMP	Sensitivity assessment; no explosive event.

Shaped charge attack (see WAG-11, Section 3.3) is not yet a required test. Preliminary testing in generic hardware may be requested before weapon development, but is not usually required unless the explosive/propellant differs appreciably from those already qualified, ie this is an optional comparative test schedule [12]. A qualification of the energetic material [13] must precede any use in weapon development.

An update on policy implementation has recently been issued [10]. After a restatement of the IM policy from Reference [3], a proviso is added that where technology is not available to comply with the IM policy through the use of less sensitive energetic materials and improved hardware designs, the weapon project manager shall identify methods of protecting the munition and ways to mitigate damage to aircraft and ships. Practical constraints include, but are not limited to, performance requirements, affordability, remaining service life and technical feasibility. If a munition cannot be designed to be insensitive, it will be designed to be a "less sensitive munition", defined as meeting one or more of the criteria required for insensitive classification, but not passing all criteria (see further comment in Section 5.7).

4.2 US Air Force Policy

The principal focus is on general purpose bombs and their effect on quantity-distance requirements associated with storage of munitions at bases in Europe. The program is well advanced [14]. Some reduction in performance and storage density is acceptable. Solutions appear to be restricted to melt-cast explosives. The problem of ordnance vulnerability when externally carried on aircraft is also being addressed by the US Navy for its aircraft.

4.3 US Army Policy

The principal interest is in gun ammunition and rocket weapons that affect the survivability of tanks and armoured vehicles. Performance must not be degraded and vehicle magazine storage capacity cannot be compromised. The main emphasis is on LOVA (low vulnerability) propellants.

4.4 US Tri-Service Joint Requirement for IM

A memorandum of agreement was signed on 8 September 1987, and is broadly similar to US Navy Policy. Mandatory tests for IM status are fast cookoff and multiple bullet impact (requirement: burning as maximum response) and sympathetic detonation (requirement: no propagation). Other tests as outlined in 4.1 are considered to be optional.

4.5 UK Policy on Insensitive Munitions

In late 1987 it was reported [15] that the UK position on IM was developing rapidly. Although much relevant experimental work was being carried out, the UK had no overall view on IM; the dominant user interest was in performance and reductions in vulnerability were not being demanded, unlike the US Navy. However the drive of US efforts and obvious commitment has led to a reappraisal of the UK view.

In mid-1987 a joint MOD UK/industry group was established to provide the basis for a UK position on IM and to make recommendations to the President of the Ordnance Board. The group was drafting its first report (in late 1987), and recommendations were summarised as:

1. UK should adopt the general principles of the US IM initiative;
2. the operational impact of the introduction of IM into service needs to be established by operational analysis;
3. research to support the initiative is required to quantify user benefits, define credible and achievable tests and criteria, provide guidance to designers and develop appropriate energetic and non-energetic materials technologies.

The Royal Navy (RN) has a policy that munitions embarked on HM ships shall be so designed that explosion or detonation does not occur in the Standard Liquid Fuel Fire test. Slow cookoff is also seen as a credible threat by RN, and introduction of a test of this type is seen as desirable [16].

4.6 The NATO Countries

All the NATO countries have active programs on IM, and have recently established the NATO Insensitive Munitions Information Center in Maryland, US, to facilitate policy establishment for the eventual transition to IM. The heavy US presence in Europe must lead to adoption of an IM policy consistent with that of the US due to interoperability and other strategic considerations.

5. ANSWERS TO SPECIFIC QUESTIONS FROM REF [1]

Answers to ten questions were requested by PAOC [1]; one is detailed at the start of each section 5.1 - 5.10. Some of the questions have already been answered in this document and reference will be made to the relevant section rather than repeating. The emphasis in the answers is on Australia's defence strategy and capabilities but, where appropriate, US and UK strategy is included for comparison.

5.1 What are IM - advantages and disadvantages of IM?

A concise definition of IM is given in Section 2.

The advantages are clear and they are extremely well outlined in the WAG-11 summary (section 3.3). To summarise, real cost benefits will accrue through platform safety/survivability improvements as well as reduced personnel risks throughout the entire life cycle of the munition; this includes manufacture, storage, transport and operational use. See 5.2 for further elaboration. Australia's limited number of high value sea and air platforms for maritime operations, and their highly trained crews, makes survivability improvements extremely desirable. In addition, enhanced safety in transport will confer operational advantages for munition supply to northern regions from the production base in the south-east.

The disadvantages of IM **at the current time** fall into three areas.

1. The explosives and propellants needed to meet insensitivity criteria are generally more expensive than current conventional fillings (see 5.4 below). In addition fitting of mitigation devices etc will also increase munition procurement costs.
2. The current production base of IM in the US (see 5.3 below for Australia) is inadequate to meet wartime needs for mass usage munitions such as GP bombs.
3. Retrofit of in-service weapons with IM technology currently available (insensitive explosive fillings, mitigation devices etc) still does not result in some cases in meeting all acceptance criteria. Particular difficulties are experienced with high charge/mass ratio munitions, and the slow cookoff* and sympathetic detonation tests. Performance reduction can overcome this, but the users are not (with the exception of USAF, Section 4.2) prepared to accept this.

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* Slow cookoff simulates the environment experienced by a munition in a magazine adjacent to a fire. Fast cook-off simulates a munition in a fuel fire; case venting occurs more readily under fast cook-off, resulting in general in a milder response.

It is anticipated that R & D currently underway on continuous processing techniques will alleviate 1 and 2, while technology breakthroughs from IM R & D will overcome 3.

5.2 Why did the US Navy adopt IM?

The US Navy position is summarised in the beginning of section 4.1: to reduce platform vulnerability in war, and to enhance aircraft carrier survivability during on-board fire.

This will be elaborated further in the Australian context, since Australia does not possess an aircraft carrier. The other Naval system modelled during the IHEP study [4] was a Virginia class GM Cruiser. Threats from Styx missile, fragmenting warhead and torpedo were evaluated. A significant reduction in ship sinking probability was predicted through use of IHEP. This result will be directly transferrable to the RAN's fleet which consists, in general, of smaller platforms.

Again, in the Australian Army context, the US IHEP study concentrated on MBTs and 155 mm self-propelled howitzers; the latter we do not possess, and the former are low strategic priority. However APCs, ground launched rocket systems and helicopters were also studied and substantial reductions in vulnerability/lethality were predicted for substitution of current weapons by IHEP.

Aircraft vulnerability modelling for the IHEP study was carried out on the F-4 aircraft. It was concluded that replacement of the current externally carried munitions by IHEP equivalents would result in a small to substantial reduction in vulnerability area, depending on the weapon system.

To further emphasise, we quote from the IHEP study conclusions [4]; "The problems identified and conclusions drawn would in large measure be applicable to trains, transport ships, ready magazines and strike staging areas". Operational advantages for transport to and storage in northern Australia would clearly be realised.

5.3 Does Australia have capability of manufacturing IM and how long would it take to convert from current production to IM?

In DOA87 [2] the contribution of local ordnance production to our defence self-reliance is stressed:

> "We are largely self-sufficient in .... the more common ammunition types", and
>
> "The priority requirements are ...... the provision of munitions ..... for which we could least rely on overseas supply." [17].

Specialist advice was sought from Mr Noel Tozer, Manager Project REFA. The major points from Mr Tozer's reply [18], which covered only filling operations, are abstracted below.

Australia does not have the capacity to manufacture IM, except on a very limited scale; the processing technology is very similar to cast composite propellants for which limited production capability exists, but propellant or explosive formulations incorporating nitramines (RDX or HMX ie hazard classification 1.1D) would be difficult to handle in existing propellant production facilities.

Two major facilities would need to be established.

1. Screw mixer extrusion for propellants (and PBXs in the future)

2. Specialised filling equipment including the ability to fill under vacuum.

In addition, if HMX was required there is now no production capability* while specialised grades of RDX are not produced at present, but current plant could be adapted to do this.

Many of the binder/plasticiser ingredients would not be available locally, but this has been overcome for cast composite propellants and is not seen as a major problem.

In summary, an injection of several million dollars would be needed to establish an adequate capability for loading IM in Australia.

Timescale for introduction was estimated as at least three years to identify, select, acquire, install and commission process plant following resource allocation. A further two years would probably be required to produce acceptable stores which should then be subjected to environmental testing (see later comments in Section 5.10).

For engineering aspects, two major problem areas are evident. Firstly, only very limited capability exists for manufacture of advanced rocket case technology. Secondly, although manufacturing expertise could exist for mitigation devices/technology, the technology base is at present totally inadequate to support this. The timescale for establishment of this capability would be within those necessary for establishing the loading facilities described above.

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* In the authors' opinion, HMX based PBXs or LOVA propellants are unlikely to be required for production of ordnance in Australia.

5.4 Are there cost penalties?

Some comment has already been made in Section 5.1, and an outline of indicative relative costs will be made here.

The US IHEP study critically examined cost analysis [4]. It was concluded that "*for almost all systems studied, the 10 year life-cycle costs increased if insensitive explosives or propellants were substituted for the current fill*". The system chosen for detailed evaluation was the Mk 82 bomb. The 10 year life cycle costs were dominated (86% of total) by material and loading costs. Indicative (1979) loading costs* were:

. current melt-cast explosives, US $1.50 per lb
. cast-cured explosives, US $5 per lb
. pressed explosives, US $7 per lb

The higher loading costs of cast-cured and pressed polymer bonded explosives (PBXs) was seen as a major problem which must be overcome if these materials were to be used on a large scale.

An indicative Australian loading cost for a Mk 82 bomb can be made from estimates provided for an MRL mine feasibility study [19]. For a 150 kg warhead, similar in size to a Mk 82, the relative costs were estimated as (1987 figures);

H-6 (RDX TNT/Al/wax 45:30:20:5); A$1.66 k
PBXN-109 (RDX/Al/binder 65:25:10); A$3.77 k
PBXN-105 (RDX/AP/Al/energetic binder 7:50:26:17); A$5.76 k

PBXN-109 is a general purpose insensitive warhead filling qualified in US Mk 82 bombs, and PBXN-105 is the filling in the Mk 48 torpedo warhead.

Information given to one of the authors (RJS) during an overseas visit to RO Glascoed in the UK was that loading costs of PBXW-115 (RDX/AP/Al/binder) would be competitive with Torpex (RDX/TNT/Al 42:40:18) [20].

Considerable R & D efforts are now being made, particularly in the US and Germany, to reduce processing costs by continuous processes (rather than batch) such as screw extrusion. Cost differentials between melt-cast and PBX fillings are thus likely to diminish in the future.

However, it should be stressed that the increased cost of IM can be offset by a number of factors. These include wartime reduction in catastrophically killed weapon platforms and (particularly for Australia) their trained crews, avoidance of peacetime accidents with all the associated adverse environmental and political consequences, and

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* Costs cited in this section are estimated to cover materials, processing and filling.

an enhanced readiness posture facilitated by the ability to store more ammunition in vital asset points. The IHEP study team concluded that "the use of insensitive materials would be cost-effective in many of the systems studied if it were possible to quantify the cost savings associated with these factors" [4].

5.5 Can it (IM) be retrofitted?

A key component of the US Navy policy is to retrofit existing weapons systems so as to achieve IM status (but see comments at end of Section 5.7). Requirements and procedures to achieve IM status by design modification have been defined [7]. At 1 April 1985 there were 37 US Navy munition ordnance systems being made insensitive, with the number expected to rise ultimately to over 200 [8].

A US Navy priority list of fifteen munitions for retrofit has been published [8]. The following have been selected from this list as relevant to the ADF inventory, and particular attention is drawn to three:

> "In the air our long range strike forces will comprise squadrons of F-111C long range bombers and F/A-18A multirole aircraft, and our P3C Orions. In all, over one hundred of these aircraft will be armed with the Harpoon anti-ship missile and our F/A-18As will carry the Sidewinder and Sparrow air-to-air missile and a range of other smart weapons." [21].

USN Priority/Munition		Fix	Start
1.	5"/54 shell	HIFRAG/LOVA	1990
2.	GP Bombs	PBX fill, fix fuze	1988
4.	Harpoon	PBX fill, thermal coat motor, develop new motor	1991
7.	Mk 46 Torpedo	Risk assessment under review	TBD
10.	Sparrow	Thermal coat, new motor, vent booster	1990
12.	HARM	Thermal coat, new motor	1990
13.	Sidewinder	R & D required	1990
?	Standard missile	Booster, sustainer, motor and ordnance	?

When each of these "fix technologies" become developed, and assuming production facilities were established and the necessary R & D to guide production had been carried out, Australia could retrofit using the prescribed "fix".

One current example of retrofit is AMRAAM for the US Navy. After experiencing problems in the fast cook-off test, the AMRAAM AIM-120A for US Navy is now fitted with a Thermally Initiated Venting System (TIVS). TIVS is an externally fitted mitigation device consisting of a Linear Shaped Charge containing HNS explosive, with a thermal sensor and initiator. The function of the TIVS is to vent the rocket motor chamber when engulfed in a fuel-fire and prevent the previously occurring

deflagrations/explosions. It has been shown to be successful, reducing the maximum level of reaction to burning. Note however that this is a "fix" for fast cook-off only. The technology is not sufficiently developed at this time to allow AMRAAM to pass all IM criteria (see Section 5.1).

Australia has no current technology base R & D on mitigation systems/devices. This is clearly a critical technology gap which must be addressed.

5.6 Are there priorities in requirements for converting to IM ie GW before conventional (unguided)?

In the US Navy, priorities for conversion to IM do not appear to be based on munition type. For example, in the priority list from Reference [8] which was part produced in section 5.5, 10 of the top 15 priority items were GW. The attraction of GW is probably that they are relatively expensive, low production, low usage rate munitions where the explosive filling constitutes a relatively minor part of the total cost; the increased IM cost would therefore show up as a smaller percentage of the total cost. However other priorities such as available technology (to achieve IM), threat/hazard significance, stage in life cycle and projected (IM) replacements would clearly also figure prominently in such decisions.

Australia's priority would be very much dictated by US decisions on retrofits. GW would be attractive because of our reliance on precision standoff weapons [22] to enhance platform survivability. In addition, our limited inventory and production capability would be more closely matched than for a bulk-use unguided munition.

5.7 Impact of US Navy IM Policy on Australia Providing Explosive Ordnance to USA

The US Navy policy on foreign-sourced munitions is spelt out clearly in a number of policy documents [7-10]. Specific passages are cited:

"This instruction [7] (The Insensitive Munitions Program [8, 10]) applies to all munitions aboard Navy ships and aircraft no matter what the source of design or manufacture".

"This instruction [9] applies to explosives ashore or aboard Navy ships or aircraft, whether designed and built by the Navy or developed by other services, private industry or foreign sources and whether intended for operational use, testing, training or transport."

"........ ensure that the US Navy's policy on IM is considered in all dealings with foreign military agencies" [8].

Australian supplied munitions/ordnance will therefore have to be qualified to IM status to be accepted into US Navy service. However this impinges in a much broader sense on the Australian defence strategy in the areas of Exports and International Collaboration [2]. We quote:

"The export of defence and defence-related products can foster skills and capacity in Australian industry and reduce the costs of indigenous supply and support for the ADF." and

"..... international collaboration is now becoming increasingly common as a means of sharing risks, spreading costs, increasing market size and exploiting specialisation and economies of scale. .... collaborative projects are likely to become increasingly important for Australia." [22].

The obvious current example is Project Nulka [23]; this joint development is required to meet US Navy IM guidelines.

Waivers would be very difficult to obtain, and will become increasingly more difficult in the 1990s and beyond. From discussions held recently in the US by one of the authors (LMD) it is clear that the philosophy of waivers was introduced to allow existing munitions which may not meet the IM requirements by 1995 to remain in service. Only in unusual circumstances will a waiver be granted to any munition currently in the design stage or in the future; it is US Navy policy that IM requirements must be incorporated right from the initial munition design stage and reliance on subsequent retrofit will be strongly discouraged.

5.8 Current Australian Research into IM

All IM R & D on explosives is carried out in Explosives Division, MRL, while propellant aspects are principally conducted at Ordnance Systems Division, WSRL, with some collaborative work at MRL. The major effort in IM propulsion systems at present is associated with Project Nulka [23].

Materials/Formulations

The major US Navy strategy to achieve IM status has been to replace existing fillings by less sensitive cast-cured polymer bonded explosives (PBXs) and low vulnerability ammunition (LOVA) propellants.

Prior to commencement of the current PBX programme at MRL, studies were carried out over the period 1974-1980 in Ordnance Systems Division (then Propulsion Division), WSRL. The WSRL studies generated a technology base by familiarisation with the US formulations PBXN-106 and its aluminised version PBXW-107 [24] and PBXW-108 and its aluminised version PBXN-109 [25] (see section 5.4). Both PBXN-106 and PBXN-109 are in US service in 5"/54 shell and Mk 80 series GP bombs respectively. US R & D on the other two PBXs has been terminated [20].

Current PBX R & D at MRL is covered by three tasks:

PBX (AIR 87/156) FY 87/88 - 89/90

PBX Fillings for Large Underwater Blast Weapons (NAV 88/037) FY 88/89 - 90/91

Explosives Materials Research (DST 88/090) FY 88/89 - 90/91

AIR 87/156 is principally concerned with evaluation of the US formulation PBXN-107 (RDX/acrylic binder 86:14, RAAF inventory in HARM warhead) and its aluminised version PBXC-117; both are insensitive explosives with the potential to overcome RAAF's aerodynamic heating problems.

NAV 88/037 is primarily concerned with evaluation of the US formulation PBXW-115 (see Section 5.4), an insensitive, high performance underwater explosive which is expected to be qualified for use in US Navy mines.

R & D for an insensitive booster explosive to be used with these warhead materials is also covered under these tasks.

R & D on insensitive melt-cast TNT formulations using 1,3,5-triamino-2,4,6-trinitrobenzene (TATB) and spherical nitroguanidine (SNQ) as insensitive explosive fillers is concentrating on processibility and performance of formulations optimised to maximum filler level. Assessment of the new insensitive explosive 5-nitro-1,2,4-triazolone (NTO) is also being undertaken. Both studies are carried out under DST 88/090.

IM propulsion R & D is primarily covered by two tasks:

Vulnerability of Rocket Propellants (DST 86/212) FY 86/87 - 88/89

Response of Rocket Motors to Projectile Attack (DST 86/208) FY 86/87 - 88/89

Although some R & D on formulations is carried out, the primary emphasis is on Hazards Evaluation associated with Project Nulka (ODP 88/104, Nulka Full Scale Engineering Development Support - WBS Element 11B000).

Hazard Response Evaluation

For explosives, the main effort is on cookoff for evaluation of booster and main charge response using small scale tests of 20 g and 600 g (AIR 87/156 and NAV 88/037). Thermal decomposition of the insensitive explosives NTO, NQ and SNQ is also being studied, along with modification of thermal response with polymeric binders (DST 88/090).

Sympathetic detonation induced by violently deflagrating donor rounds, and vulnerability of bare and cased munitions to shaped charge attack, are being evaluated under the tasks Munitions Safety and Disposal (DST 88/113) and Explosive Effects (DST 88/112) FY 88/89 - 90/91. Australia is the lead nation in several joint research

programs with the US. Insensitive fillings are currently not being evaluated but will be when sufficient material is available from the PBX tasks.

For propellants, the principal hazard being investigated is bullet/fragment impact, which is a realistic threat particularly to deck-stored shipboard ordnance such as Nulka.

Investigation of the development of small scale tests (modified Shotgun test, Hopkinson Bar test) to assess the response of propellants to bullet and fragment attack is carried out under DST 86/212. Typical service rocket and gun propellants have been assessed to provide baseline data for formulation of propellants with decreased sensitivity to impact ignition.

In DST 86/208, the propellants described above are loaded into end burning rocket motors of different case constructions and subjected to 20 mm Raufoss cannon fire and 7.62 mm bullet impact to assess vulnerability in the full-scale configuration.

Correlation between laboratory tests and rocket motor response is underway in order to establish an appropriate laboratory methodology. A limited number of full scale bullet and fragment impact and cookoff tests have been conducted to establish qualification capability for Project Nulka and provide preliminary information to system designers.

A number of solid propellants from WSRL have been tested at MRL for their response to shaped charge jet impact and assessment of their detonability under task DST 86/193, Solid Propellant Detonability.

New Concepts

Slapper detonators, which have the potential to permit design of simpler, low vulnerability fuzes, are being extensively investigated under DST 88/112.

5.9 Proposals for any future research into IM

Continuation of Programs Described in 5.8

R & D on IM and energetic materials must be looked on as a long term program; the timescales result from the necessity to characterise and assess at each stage of development, particularly the lengthy environmental assessments.

A number of projects described in 5.8 will have continuing resource allocation through continuation of approved tasks. These include for explosives:

PBX formulation studies coupled with hazard assessment of warhead and booster fillings from fast and slow cookoff, sympathetic detonation, shaped charge attack and also bullet/fragment attack.

Performance evaluation, particularly fragmentation and air blast measurements, will be undertaken. Corresponding evaluation for underwater performance, ie shock and bubble energy, will also be undertaken.

Slapper detonator R & D will continue, including prototype fuze development.

Programs for propellants include:

Investigation of relevant small-scale laboratory tests for determining sensitivity to bullet/fragment impact. Test data generated from existing service propellants will form the basis for development of newer formulations with decreased sensitivity. Correlation of laboratory data with full-scale results should ultimately lead to derivation of reliable small-scale tests so that only the minimum number of costly and time-consuming full-scale tests are required.

Assessment of propellant response to shaped charge jet impact will continue at MRL on a range of propellant samples from WSRL.

Technology Shortfalls that Need to be Addressed

A number of key technology areas are not covered by current or projected resource allocation, and it is the authors' belief that serious thought should be given to additional resource allocation to cover these topics. These include:

Mitigation devices, including externally fitted linear cutting and thermite charges, internal liners, intumescent coatings etc (see earlier comments in Section 5.5). Related R & D is being carried out on thermites and cutting charges for explosive ordnance disposal (DST 88/113) and other applications (MOE, ARM 86/119). In addition, TTCP PTP-3 (Organic Materials) has an active study program on intumescent coatings and some expertise still exists in Protective Chemistry Division at MRL from previous tasks. Both would provide an excellent springboard for R & D expansion on mitigation techniques.

Reactive case technology, which is currently being studied at MRL for enhanced blast performance warheads but has a number of potential advantages for IM.

Qualification to IM requirements of one or more of the cast-cured PBXs currently under study, using a generic or service warhead. This will require establishment of test facilities for environmental and rough usage assessment for PBX-filled large stores, ie hazard category 1.1D; lack of such facilities is a long-standing weakness in Australian ordnance technology. Note that Project Nulka is covered by the lesser hazard classification 1.3C.

Evaluation of the two USAF melt-cast IM fillings, AFX 1100 (TNT/Al/wax 66:18:16) and AFX 900 (RDX/NQ/Al/polyethylene wax 18:49:17:16) could be undertaken. However, these highly waxed formulations have substantially reduced performance over current fillings such as H-6 or Comp B and a statement by RAAF, for example, of acceptability of this performance decrease would be required before R & D

could be considered. It should be stressed that performance decreases are not necessary to meet IM requirements, except perhaps in the special case of USAF storage demands. Higher performing melt-cast and extrudable insensitive fillings could also be investigated.

Alternative rocket motor case construction, which will be most relevant for the next generation of weapons but could be retrofitted to existing systems.

5.10 Timescale for Implementation of Australian IM Policy

The timescale for implementation of an Australian IM policy (or policies) once adopted by the ADF would depend on a number of factors.

Firstly, implementation would almost certainly have to be user (RAN/RAAF/Army) driven, hence timing would initially have to be on the basis of their priority. Policy options are discussed in the following Section; each option would have a different timescale for implementation.

Secondly, technology base R & D, although expanding, is currently inadequate to support production, retrofit or qualification of IM. This in part results from the fact that IM has not been adopted as firm policy by the ADF; support for IM R & D within the DSTO technology base is consequently not strong, resulting in a weakened, somewhat fragmented approach.

Thirdly, viable production capacity for both filling and engineering operations needs to be established. This point was summarised in the final paragraph of Section 5.3 where a timescale of at least five years was required to install and prove production capability [18]. In addition, as stated in the previous section, it would be desirable to have an environmental test facility to support production and service use of all ordnance, and no decision has been made to establish this facility.

Given these unknowns, no timescale can be proposed. However, as stressed by Manager Project REFA [18], if RAN or RAAF are contemplating the introduction into service of IM, then action should commence without delay.

6. AUSTRALIAN POLICY OPTIONS

The advantage of IM to Australia's defence preparedness through enhanced platform survivability, transport and storage safety and related operational benefits have been described in detail in preceding sections. These advantages are in many cases available **now** without any or with only minimal degradation in weapon performance-on-target.

Regardless of Australian policy, the Australian ordnance inventory will be increasingly influenced by IM through future weapons acquisition, particularly those of US Navy origin. The strategic advantage of weapons interoperability, as well as the policy of the US Navy (and RN when adopted) as it impinges upon joint operations etc, could have a strong influence in directing RAN policy in particular.

Policy options which must be considered, include:

a. Adopt no firm IM policy at this stage. Consider each ordnance procurement or update as it arises, essentially in isolation.
b. Adopt a policy of IM in principle for specified weapons systems, eg deck-stored shipboard ordnance, ordnance externally carried on aircraft.

Note, however, that IM purchases will almost certainly involve higher procurement costs than non-IM alternatives. If a. or b. are accompanied by restrictive clauses such as non-acceptance of significant cost and/or performance penalties, both are effectively non-IM policies.

c. Adopt a broadly based IM policy, eg all ordnance carried on RAN platforms, and accept some cost and possibly performance penalties as a trade-off for increased platform survivability.

d. Adopt a comprehensive IM policy where the risk of platform loss due to accidental initiation of ordnance is given high priority in requirement specification. A defined timescale for implementation could also be incorporated.

The selection at this stage of an option for IM (or more likely, for a series of different positions selected by elements of each Service) is perhaps less important than the need for recognition that some firm policy selection is needed. The key to this recognition is the fact that new energetic materials and mitigation techniques have made available the option of increased platform survivability.

Detailed attention to the steps which have been taken to ensure that IM advances have been seriously considered in order to maximise platform survivability would go a long way towards the establishment of a practical IM policy.

7. SUMMARY

For much of this century weapons designers and users have been preoccupied with increasing cost-effective performance-on-target. The legacy of this policy is that a modern ordnance inventory consists of high performance munitions, some of which also exhibit relatively high vulnerability accompanied by unacceptably violent response to unplanned hazardous stimuli such as may be experienced in manufacture, transport, storage and operational use.

Recently developed and emerging technology has enabled development of a new revolutionary family of Insensitive Munitions (IM) which respond mildly to such hazardous stimuli. This response has been achieved, in general without performance reduction, using a variety of approaches including insensitive explosive and propellant fillings, system redesigns, active and passive mitigation devices and improved storage configurations.

Introduction of IM to Australian Service will produce real cost benefits throughout the entire life cycle of munitions. We are strategically reliant on a limited number of high value sea and air platforms, and their highly trained crews; wartime operational benefits will be realised through increased platform survivability. A realistic threat to these platforms which can be nullified by use of IM is bullet/fragment impact, and mechanical drop during loading operations, to externally carried ordnance. In addition, increased safety in transport to and storage in vital asset points will be realised. Perhaps more immediately, use of IM will minimise equally devastating problems in peacetime storage and training, and their associated political and legal consequences.

These benefits have been documented in a succession of studies [4-6]. Although our western allies are moving towards a position of adopting IM, only the US, and the US Navy in particular, has a firm policy in place: the US Navy goal for complete arsenal transition to IM is 1995 [3]. US Navy requirements for IM have been defined, test procedures to qualify both new and retrofitted existing systems to these requirements have been detailed, and a major R & D program is currently underway [7-10]. A full summary of US Navy policy and procedures can be found in Section 5.1. It now seems certain that the US Navy IM goal, which many in the ordnance business thought an impossible dream when stated in 1984, will indeed largely be achieved by 1995.

The messages for Australia are clear. IM will increasingly be adopted by our allies, and weapons systems purchased from our allies will increasingly conform with IM guidelines. If the ADF is not IM-equipped, the strategic benefits of interoperability of appropriate systems will be lost. The policy of the US Navy and RN and it impinges on joint operations etc could have a strong influence on RAN policy in particular.

We must continue R & D on IM so that expert technical advice can be given to the services to ensure the most appropriate weapons systems are purchased. As discussed in Section 5.3, if Australia is to make the maximum strategic benefits from IM, a local production base is essential. Establishment of a viable production capability will take at least five years. In addition, the lack of an environmental test facility to support production and service use is a long standing weakness for Australia which needs to be addressed. The technology base R & D coupled with production capability would also permit refurbishment, modification and maintenance f these future IM purchases, as well as retrofit of selected current systems to IM requirements.

Export sales to our allies will increasingly be required to conform with IM guidelines. Survivability/safety/invulnerability strictures will not be relaxed (and most probably will be increased), and this will impinge directly on collaborative programs such as joint developments. The latter (eg Nulka) will become more common as the cost of system developments continues to escalate.

A number of policy options have been outlined in Section 6. For emphasis, the desirable options (b.–d.) are restated here in full:

b. Adopt a policy of IM in principal for specified weapons systems, eg deck-stored shipboard ordnance, ordnance externally carried on aircraft.

These examples specifically refer to ordnance systems in external stowage and hence vulnerable to bullet/fragment attack in wartime, but also during peacetime through terrorist attack. Other realistic threats which would be nullified by introduction of IM are cited throughout the text. This policy represents the bare minimum, as long as overly restrictive cost (in particular) and performance penalty requirements are not included.

c. Adopt a broadly based IM policy, eg all ordnance carried on RAN platforms, and accept some cost and (possibly) performance penalties as a trade-off for increased platform survivability.

d. Adopt a comprehensive IM policy where the risk of platform loss due to accidental initiation of ordnance is given high priority in requirement specification.

Options c. and d. are preferred positions; c. could be adopted in principal immediately and phased in, extending ultimately to d. over time. This could be implemented on a long-term basis within budgetory restrictions, or a defined timescale for implementation could be incorporated.

Finally, to reiterate from Section 6, detailed attention to the steps which have been taken to ensure that IM advances have been taken into account in order to maximise platform survivability would go a long way towards the establishment of a practical IM policy.

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AUTHOR(S)	CORPORATE AUTHOR
Robert J. Spear and Louise M. Davis	Materials Research Laboratory Defence Science & Technology Organisation PO Box 50 Ascot Vale Victoria 3032

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ABSTRACT

This report has been prepared in response to a request from President, Australian Ordnance Council (PAOC), for a working paper to serve as a basis for derivation of an Australian policy on Insensitive Munitions (IM). IM are defined (Section 2) and the background studies confirming the operational and strategic benefits are summarised (Section 3). Overseas service/user policies are described (Section 4), particularly those of the US Navy which has the most clearly defined IM policy. Ten questions from PAOC dealing with background issues, priorities, possible cost penalties and methodology for meeting IM guidelines, Australian production capabilities and current and future R & D, implementation timescale and impact on munition exports and collaborative programs are answered (Section 5). Policy options are presented (Section 6) followed by a summary and recommendations for implementation such that the potential benefits from IM for Australia's defence preparedness and self reliance can be achieved (Section 7).

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